S2M2 Study- Executive Summary Report

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S2M2

ESR EXECUTIVE SUMMARY REPORT

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CHANGE RECORDS

ISSUE	DATE	§ CHANGE RECORDS	AUTHOR
01	21/06/2021	First issue, for Final Review	M. Berga, A. Ferri
02	01/07/2021	Second issue implementing FR comments	M. Berga, A. Ferri

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1 SUMMARY OF THE S2M2 STUDY

The study “Small Satellite Missions to Mars-An Architectural Study” performed by the TAS team, composed of the two entities:

1. Department Observation and Science Italy as Prime contractor of the activity
2. Politecnico of Milano in charge for the Mission Analysis and the budgets

Several possible solutions have been presented for the two main mission concepts proposed by the SoW:

- Mars Communication Constellation
- Mars Science Orbiter

The Team selected the Mars Science Orbiter mission as the concept to be analysed, on the basis of both technical reasons (launcher capabilities vs adopted heritages and S/C mass) and programmatic (extremely short time available for development with launch in 2028, and cost budget limitation).

In order to meet the requirements and increase the performances, alternative trajectories have been proposed and compared to the ones reported in the CDF study, as well as several different mission architectures in order to outline which could be suitable to fit the requirements, in particular the cost and schedule ones, assumed as the drivers for the activity, which was carried out on the basis of pure design to cost approach. It is expected that the cost limitation can be pursued by a strict recurrence approach with only few limitation on TT&C and power.

2 SELECTION OF THE MISSION ARCHITECTURE

The selected architecture is the MSO, which has the objective to characterize the surface of Mars, and, in particular, human landing sites and perform data relay. The operative trajectory is a Sun-synchronous orbit which ensures a full coverage of Martian surface within 7 days. The orbital parameters are reported below.

Table 2-1: Operative trajectory orbital parameters.

Semi-major Axis [km]	Eccentricity [-]	Inclination [deg]	LTAN [h]	Argument of Pericenter [deg]
3716	0.009	92.76	15:00	270

For station keeping, a preliminary value of 2 m/s per year is considered, due to the very low orbital perturbations within the 6 years of the extended mission.

The mission scenario is composed by the following phases:

- **Earth Departure,** the selected strategy for the Earth escape consists of a launch in HEO orbit (900000x250 km @ 6° inclination), followed by a two-manoeuvres escape strategy
- **Interplanetary trajectory,** ballistic
- **Mars Orbit Insertion,** the spacecraft arrives at Mars on a hyperbolic trajectory with a C3 that depends on the exact launch date and on the Time of Flight. The target Mars Insertion Orbit is a 4 Sol Elliptical Orbit, and the capture strategy includes two maneuvers
  - A first strong pericentric maneuver to close the orbit
  - A second small apocentric maneuver to adjust the pericenter altitude
- **Apocenter Lowering,** in order to contain the time required by the Aerobraking and to reduce the thermal and aerodynamical loads, a first powered descent is introduced
- **Aerobraking,** an aerobraking maneuver is considered to reduce the ΔV costs to reach the operative orbit
- **Operative orbit,** with a lifetime of 4 years
- **Disposal phase,** at the end of the operative life, a disposal maneuver is performed, to increase the altitude and ensure 50 years of orbital decay before final atmospheric re-entry.

3 TECHNICAL APPROACH : SUMMARY OF SPACECRAFT DESIGN AND OPERATIONS

The technical approach for the full space segment and equipment provision is a strict design to cost one based on the usage of COTS components limiting as much as possible the platform modifications. The selected design for the MSO mission is based on a composite spacecraft with two main elements: a Scientific Orbiter (SO) and a Propulsion Module (PM), both equipped with chemical propulsion.

The SO is based on HE-R1000 that is a 3 axis stabilization platform that integrates in a single main module all the BUS units, the propulsion subsystem and the payload equipment, including the pertinent appendages. the HE-R1000 physical architecture well pre-arrange the “stack ability” option for providing a three S/C launch set. This platform has an outstanding performance and customization capabilities to respond to the customer requirements, minimizing non-recurring cost, with a dry mass lower than 550 kg and a payload capability up to 400 kg. It offers reliability of 0.9@7 years, with a Power capability of 2000 W Solar array (BOL) at Earth and a 60-80 Ahr battery.

The propulsion capability is hydrazine based with a modular tanks supporting structure allowing polar/equatorial mounting and for a tanks capacity range from 35 to 160 kg. The system is a blow-down full redundant dual branch with 4, 6, or 14 RCTs.

The platform has high pointing accuracy (0.01°) and knowledge (0.003°), and allow high precision position real time knowledge better than 10 m, on 3 axes (3 sigma).

For the Propulsion Module we consider the OIM that is a propulsive module will be used in the MSR-ERO mission and will be procured as a pure recurrent element, without implementing any modification. The OIM is a bi-propellant MMH/MON-3 system with pressure regulation allowing it to operate both in regulated and blowdown modes.

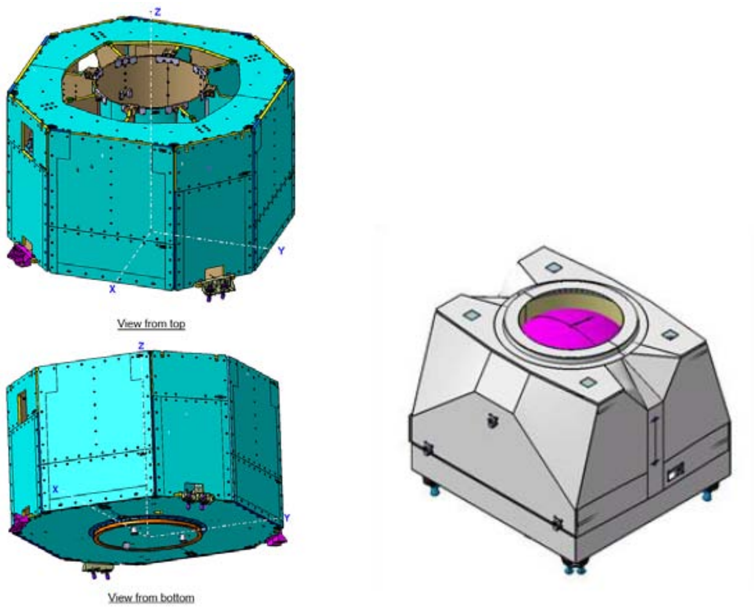


Figure 3-1 – HE-R1000 and OIM

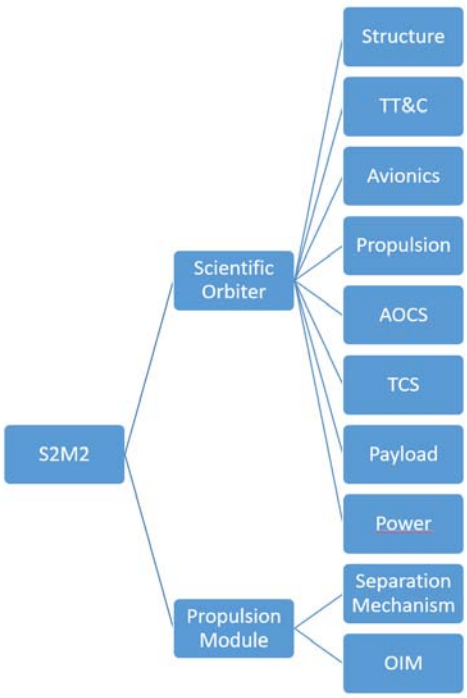


Figure 3-2 – MSO Product Tree

4 SUMMARY OF PERFORMANCE ANALYSIS

In the following tables, the main budgets are reported.

Table 4-1 – Mass Budget

ORBITER	S\S	Acronym	Description	Quantity	Unit Mass (Kg)	Margin	Unit Mass with Margin (Kg)	Total Mass with Margin (Kg)	
	STRUCTURE								187.4
			Primary Structure	1	86.2	5%	90.5		
			Secondary Structure	1	70.7	5%	74.2		
			Tertiary Structure	1	19.4	5%	20.4		
			Miscellanea	1	2.2	5%	2.3		
	TCS			1	19.1	5%	20.0		20.0
	PROPULSION								28.3
		TNK	Tank	1	16.1	5%	16.9	16.9	
		FDV	Fill and Drain Valve	3	0.1	5%	0.1	0.2	
		FVV	Fill and Vent Valve	1	0.1	5%	0.1	0.1	
		LF	Line Filter	1	0.7	5%	0.7	0.7	
		LV	Latch Valve	2	0.5	5%	0.5	1.0	
		PV	Pyro Valve	2	0.4	5%	0.4	0.8	
		PT	Pressure Trasducer	3	0.8	5%	0.8	2.4	
		PIP	Pipes	1	2.9	5%	3.0	3.0	
		ENG	ME 20N	1	0.7	5%	0.7	0.7	
		ENG	RCT 1N	8	0.3	5%	0.3	2.5	
	HARNESS								28.1
		HRN	Harness	1	28.1		28.1	28.1	
	EPS								122.5
		BTA	Battery Assembly	1	23.3	2%	23.8	23.8	
		PCDU	PCDU	2	6.2	5%	6.5	13.0	
		SADM+Yoke		2	8.3	5%	8.7	17.4	
		SAW	Area per wing 4.77 m2	2	32.5	5%	34.1	68.3	
	AVIONICS								57.3
		IPAC	Integrated Power Avionic Communication	1	17.5	6%	18.6	18.6	
		STT	Star Tracker	4	1.8	2%	1.9	7.5	
		IMU	Inertial Management Unit	1	4.9	5%	5.1	5.1	
		FSS	Fine Sun Sensor	4	0.0	2%	0.0	0.1	
		RW	Reaction wheels	4	6.0	8%	6.5	26.0	
	TT&C								102.6
		X-DST	[DTE] Transponder	2	3.3	5%	3.5	6.9	
		TWTA	[DTE] Amplifier	2	2.1	5%	2.2	4.4	
		HGA	[DTE] High Gain Antenna	1	9.5	5%	10.0	10.0	
		HGA APM	[DTE] HGA Pointing Mechanism	1	47.6	5%	50.0	50.0	
		RFDN	[DTE]	1	14.3	5%	15.0	15.0	
		LGA	[DTE] Low Gain Antenna	3	0.2	5%	0.2	0.6	
		Transceiver	[Proximity]	2	6.3	5%	6.6	13.2	
		LGA UHF	[Proximity]	1	2.3	5%	2.4	2.4	
	PAYLOAD								46.2
		PAY	Payload allocation	1	46.2		46.2	46.2	
	SEP. MECH.								16.5
		Sep. Mech	Clamp band + sep. Springs	1	15.0	10%	16.5	16.5	
							Total Dry Mass		609.0
							System Margin	20%	121.8
							Dry Mass with Margin		730.8
							Propellant		37.2
							Total Wet Mass		768.0

OIM	S\S	Acronym	Description	Quantity	Unit Mass (Kg)	Margin	Unit Mass with Margin (Kg)	Total Mass with Margin (Kg)	
	I/F								19.3
		TRST	Transition Structure	1	17.5	10%	19.3		
	OIM			1					520.0
		OIM	Orbit Insertion module (recurrent)		520.0		520.0		
							Total Dry Mass		539.3
							System Margin	20%	107.9
							Dry Mass with Margin		647.1
							Propellant		1784.9
							Total Wet Mass		2432.0
							MSO Total Wet mass		3200.0

Table 4-2 – Power Budget

ORBITER	S\S	Acronym	Description	Quantity	Power demand on cruise [W]	Power demand on Mars during SUN DTE ONLY [W]	Power demand on Mars during SUN DTE+UHF [W]	Power demand on Mars during ECLIPSE [W]
							~ 10 min per orbit	
	STRUCTURE			1				
	TCS			1	50	50	50	97
	PROPULSION				2	2	2	2
		TNK	Tank	1				
		FDV	Fill and Drain Valve	3				
		FVV	Fill and Vent Valve	1				
		LF	Line Filter	1				
		LV	Latch Valve	2				
		PV	Pyro Valve	2				
		PT	Pressure Trasducer	3				
		PIP	Pipes	1				
		ENG	ME 20N	1				
		ENG	RCT 1N	8				
	HARNESS							
		HRN	Harness	1				
	EPS				65	60	60	40
		BTA	Battery Assembly	1	5	0	0	0
		PCDU	PCDU	2	40	40	40	40
		SADM+Yoke		2	20	20	20	0
		SAW 1482x1610	Area per wing 4.77 m2	4	-	-	-	-
	AVIONICS				204	204	204	144
		IPAC	Integrated Power Avionic Communication	1	100	100	100	100
		STT	Star Tracker	4	9	9	9	9
		IMU	Inertial Management Unit	1	1	1	1	1
		FSS	Fine Sun Sensor	4	34	34	34	34
		RW	Reaction wheels	4	60	60	60	0
	TT&C				210	210	291	70
		X-DST	[DTE] Transponder	2	48	48	48	32
		TWTA	[DTE] Amplifier	2	139	139	139	18
		HGA	[DTE] High Gain Antenna	1	0	0	0	0
		HGA APM	[DTE] HGA Pointing Mechanism	1	23	23	23	20
		RFDN	[DTE] Radio Frequency Distribution Network	1	0	0	0	0
		LGA	[DTE] Low Gain Antenna	3	0	0	0	0
		Transceiver	[Proximity]	2	0	0	81	0
		LGA UHF	[Proximity] Low Gain Antenna	1	0	0	0	0
	PAYLOAD				5	100	100	5
		PAY	Payload allocation	1	5	100	100	20
	SEP. MECH.							
		Sep. Mech		1				
			Total Power demand		536	626	707	358
			System Margin		15%	15%	15%	15%
			Losses		5%	5%	5%	5%
			Total Power demand with Margin		643	751	848	430

OIM	S\S	Acronym	Description	Quantity	Power demand on cruise [W]	Power demand on Mars during SUN [W]	Power demand on Mars during SUN [W]	Power demand on Mars during ECLIPSE [W]
	I/F			1				
		TRST	Transition Structure					
	TCS	TCS	Thermal Control System	1	350	0	0	0
			Main Propulsion TCS		350	0	0	0
	PROPULSION	PRS	Propulsion	1	50	0	0	0
			OIM Propulsion		50	0	0	0
	AVIONICS	AVC	Avionics	1	10	0	0	0
		PIU	Power Interface Unit		10	0	0	0
			Total Power demand		410	0	0	0
			System Margin		15%	15%	15%	15%
			Losses		5%	5%	5%	5%
			Total Power demand with Margin		492	0	0	0
			Total Power demand with Margin		1135	751	848	430

Table 4-3 – Delta-V Budget

Phase	Maneuver	ΔV [km/s]	Gravity Losses Policy	ΔV (with Gravity Losses) [km/s]	Margin Policy	ΔV (with Gravity Losses and margin) [km/s]
Earth Escape	Plane change	0.146	0%	0.146	10 m/s	0.156
	Pericentric maneuver	0.524	10%	0.576	5 %	0.605
Mars Capture	Pericentric maneuver	0.992	10%	1.091	5%	1.146
	Apocentric maneuver	0.014	0%	0.014	10 m/s	0.024
Aerobraking	Apocentric Lowering	0.136	10%	0.149	5%	0.157
	Walk-in	0.006	0%	0.006	5%	0.0063
	Pericenter maintenance	0.00116	0%	0.00116	100%	0.001218
	Walk-out	0.0603	0%	0.0603	5%	0.06348
Operational Orbit	Station keeping	0.002	0%	0.002	100%	0.004
Disposal	Apocentric maneuver	0.005	0%	0.005	10 m/s	0.015
	Pericentric maneuver	0.005	0%	0.005	10 m/s	0.015
TOTAL [km/s]	-	**1.891**	-	**2.055**	-	**2.193**

Table 4-4 – Propellant Budget

MSO (2028)		HEO	LVA	
Launcher Performance	*A62*	3200	100	
Launcher Margin		0.0%		
MSO		920.1	Payload	203.9
MSO Propellant		46.9		
OIM Dry Mass		647.1		
OIM Prop. Mass		1586.0		
Launch Mass	[kg]	3200.0		

EVENT		ΔV [m/s]			Mass [kg]			
EVENT name		ΔV [m/s]	ΔV Margin [%]	Total ΔV [m/s]	Main Propellant	Thruster Propellant	Dry Mass staged	Remaining Mass
								3200
LEOP	Main	0	0%	0	0	0		3200
HEO departure	Main	761	0%	761	689	0		2511
MOI	Main	1170	0%	1170	781	0		1730
Apoares Lowering	Main	157	0%	157	84	0		1645
Staging	YES				31	-	647	967
Aerobraking	Thruster	71	0%	71	0	31		936
Station Keeping	Thruster	4	0%	4	0	2		934
Disposal	Thruster	30	0%	30	0	13		921
Residuals					*0*	*1*		**920**
TOTAL		2193		2193	1586	47	647	

The baseline configuration assign to the payload the following allocations:

- POWER:
  - 100W (sunlight)
  - 20W (eclipse)
- MASS:
  - 46.2 kg

In order to increase the resources available without modifying the design some possibilities can be evaluated. Regarding the Power, as reported in the Power Budget (see**Error! Reference source not found.**), the high power consumption of the TT&C for the DTE and Proximity is a driver so limiting the communications windows (i.e. skip the communications on some pass) allow the allocation of more power to the Payload.

Regarding the mass, there are two main contributor to the increase of the propellant load (see par.**Error! Reference source not found.**):

- The 2030 launch opportunity DV, which is the highest in comparison to the others ones
- The presence of an Apoares Lowering maneuver

Comparing the different combination of the points above, the payload allocation can vary as reported in the table below.

Table 4-5 – Payload mass allocation

Payload [kg]	2028	2030	2033
1 Sol	203.9	46.2	100.5
4 Sol	272.2	106.3	163.4

If can be excluded the 2030 opportunity as a backup solution, the minimum payload allocation increase up to 100 kg.

If a longer Aerobraking phase is sustainable, the payload allocation raise up to around 164 kg.

5 PROGRAMMATIC APPROACH

The full approach for S2M2 is based on the possibility to procure two elements already developed for two other missions:

- The propulsion module inherited from MSR ERO (Fig. 2-1): full recurrent. It will be manufactured and tested starting close to the delivery of the OIM for MSR (in order to keep team, GSE and facilities, procurement of equipment and parts active in continuity with MSR ERO)
- The Science Orbiter inherited from a HE-R1000 (Fig. 2-2)TAS LEO - platform used for Earth Observation (e.g. commercial products). In this case: the S/C is kept but with some modifications which have to be introduced in order to comply with a mission to Mars:
  - o the TT&C will be completely replaced to be sized for the Earth-Mars distance and will be inherited from other missions to Mars, (EXM)
  - o An Inertia Measurement Unit
  - o A new battery using the same cells as the original battery, but properly sized (larger)
  - o 2-wings rotating solar panels with yokes and SADM, and made more robust for aerobraking
  - o A 20N engine in addition to the original 4 x1N thrusters
  - o A separation (pyro) mechanism and adapter at the interface between the two modules, for release of OIM once at Mars
  - o Software updates

Figure 5-1MSR ERO OIM

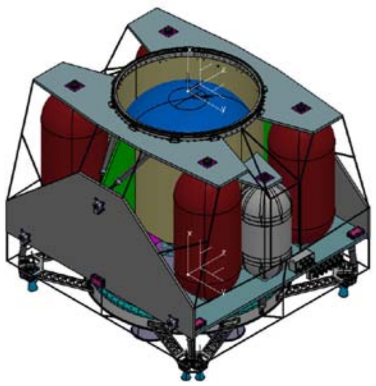
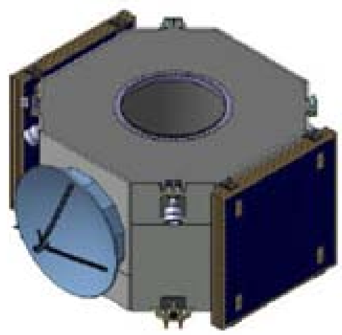


Figure 5-2 HE-R1000 platform



As for the OIM, the completion of its qualification process for the MSR ERO mission is currently expected by December 2025, exactly when it would be expected to have the authorization to proceed to the implementation phases of the S2M2 programme. So, it will be presumably possible to start the procurement of a full recurrent of OIM as needed for S2M2.

As for the Mars Science Orbiter, based on the HE-R1000, it will partially qualified as well. This spacecraft is being procured for LEO missions, and is currently entering production for a specific case of earth observation. As not all its subsystems will be fully inherited for S2M2, we can assume that it will be provided with a partial qualification. Namely, the mechanical structure, the thermal control system, the data handling system based on IPAC processor will be fully qualified. The electrical power system will be partially refurbished (at Mars we need adjustable solar arrays , with higher robustness for holding up the aerobraking phase), the propulsion will be endowed with an additional 20N thruster. The TT&C will be completely inherited by EXM TGO. As for the mechanical interface between the OIM thrust cylinder and the MSO, there will be an interface cone and ring with pyro (for separation at Mars) from the 1194 mm thrust cone of the OIM to the 937mm thrust cone of the MSO (HE-R 1000).

This approach is a pure design-to-cost one, and the procurement should be based on:

- Full endorsement of the qualification of the two modules: OIM as a pure recurrent, MSO for all the recurrent parts. Those that are new to the HE-R1000, (e.g. TT&C) are anyway off the shelf equipment with large heritage, so qualification is not an issue.
- Direct negotiation with the entities which already procured equipment in the “original” programmes
- Engineering “review of the design” activities, fully carried out in phases A and B
- Testing and verification activities very limited:
  - assumption will be that all the testing and verification carried out in the original programmes will be assumed as valid also for S2M2
  - complete tests and verifications will be performed on the new items only
  - Qualification and acceptance will be performed at Composite level only

TRL are completely in the range 7 to 9, no new development is envisaged. The European UHF is currently under development, (TRL3) and will not be charged as a development for MSO; which is foreseen for launch in 2028 in this architectural study.

The industrial consortium will have to be built up by maximizing the participation of those industrial entities already involved in the respective heritage programmes, in order to take advantage of the developed skills and implement all the lessons learned in the new programme.

6 DEVELOPMENT APPROACH

The usual approach applied in building and testing a spacecraft should be slightly reviewed wrt the conventional planning. In Fig. 6-1 is a scheme illustrating the preliminary flows for development and procurement, based on a PFM approach in terms of module philosophy with a reserve on the need of an EQM for functional qualification of design and I/F and EMC tests (as HE-R1000 is a S/C qualified for LEO mission only).

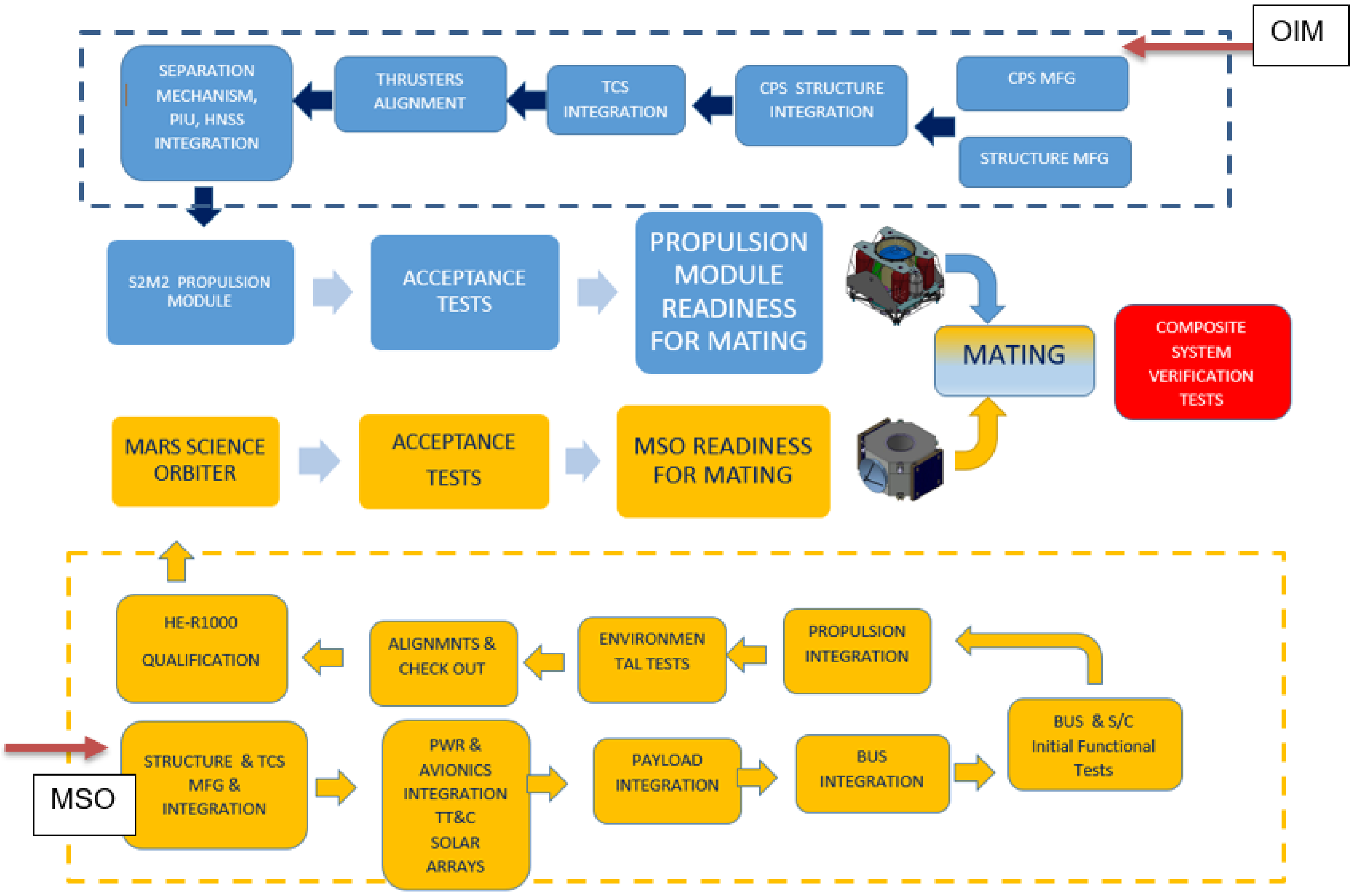


Figure 6-1 S2M2 PRELIMINARY DEVELOPMENT FLOWS SCHEMATIC (phases C and D)

7 SCHEDULE

The following tentative preliminary schedule has been prepared.

Phase A/B1 : 1-year for detailed mission analysis and complete review of the two heritage projects documentation and customization to S2M2 Proposal preparation

Phase B2 : 11 months for detailed review and preparation of the specification and the preparation of all the procurements documentations, agreements, contracts for all the needed items, completion at PDR. All the papers shall be ready for signature.

Phase C: composed by an ADVANCED C, duration around 9 to 10 months dedicated to:
The procurement of Long Lead Items (mainly the CPS), and a Completion phase C of 6 months for selection, review of the project and CDR.

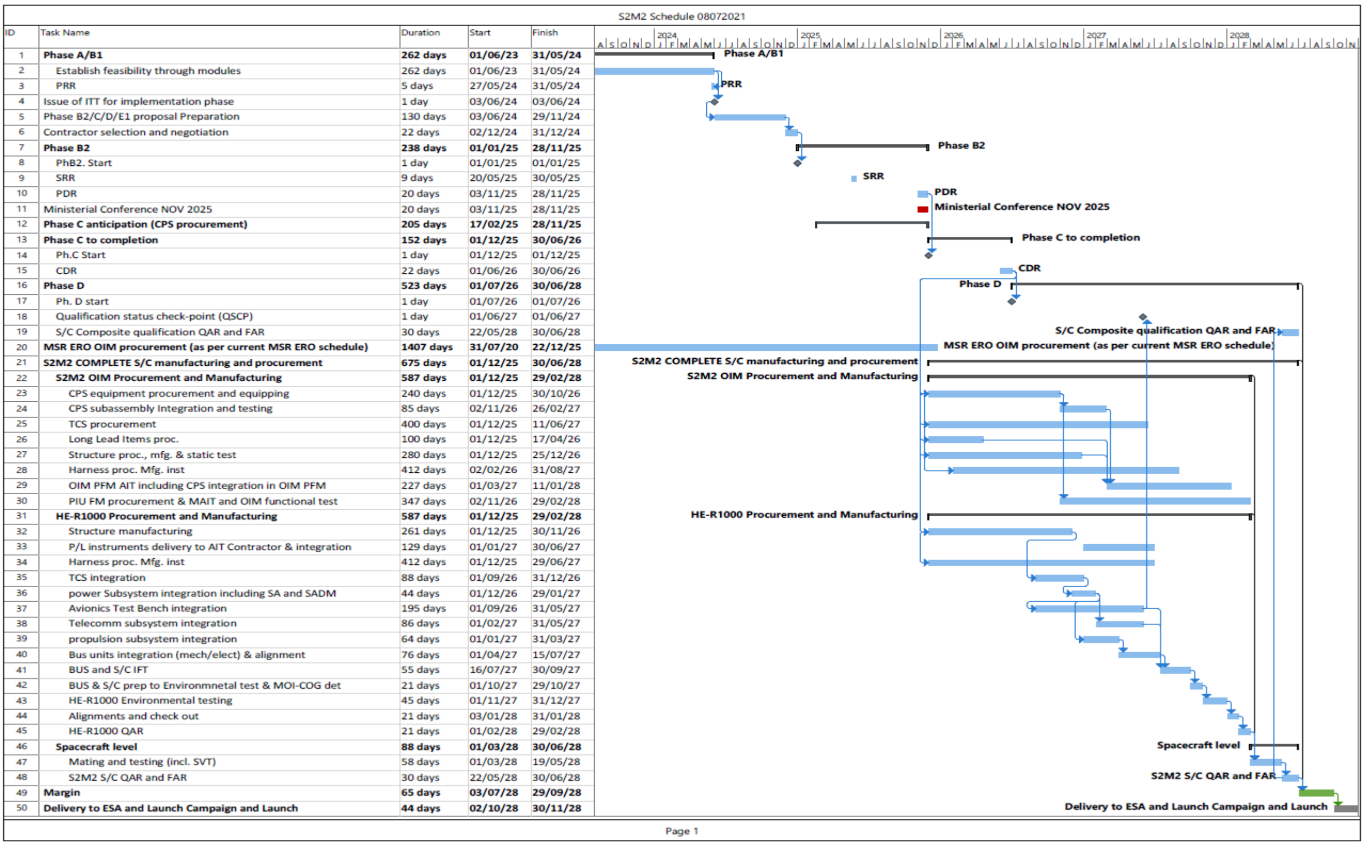
Phase D: 2 years for manufacturing and testing

Margin: 2 months ESA margin before going into launch campaign

Launch campaign : 3 months

Schedule drivers are:

- CMIN on Nov 2025, before which no implementation can be carried out (otherwise said, Phase C could not be started)
- Launch date on Nov 2028,
- Availability of the CPS equipment (linked to an early ATP) soon after the CMIN
- Availability of the OIM Structure (linked to an early ATP) soon after the CMIN



S2M2 Schedule 08072021

ID	Task Name	Duration	Start	Finish
1	**Phase A/B1**	**262 days**	**01/06/23**	**31/05/24**
2	Establish feasibility through modules	262 days	01/06/23	31/05/24
3	PRR	5 days	27/05/24	31/05/24
4	Issue of ITT for implementation phase	1 day	03/06/24	03/06/24
5	Phase B2/C/D/E1 proposal Preparation	130 days	03/06/24	29/11/24
6	Contractor selection and negotiation	22 days	02/12/24	31/12/24
7	**Phase B2**	**238 days**	**01/01/25**	**28/11/25**
8	PhB2. Start	1 day	01/01/25	01/01/25
9	SRR	9 days	20/05/25	30/05/25
10	PDR	20 days	03/11/25	28/11/25
11	Ministerial Conference NOV 2025	20 days	03/11/25	28/11/25
12	**Phase C anticipation (CPS procurement)**	**205 days**	**17/02/25**	**28/11/25**
13	**Phase C to completion**	**152 days**	**01/12/25**	**30/06/26**
14	Ph.C Start	1 day	01/12/25	01/12/25
15	CDR	22 days	01/06/26	30/06/26
16	**Phase D**	**523 days**	**01/07/26**	**30/06/28**
17	Ph. D start	1 day	01/07/26	01/07/26
18	Qualification status check-point (QSCP)	1 day	01/06/27	01/06/27
19	S/C Composite qualification QAR and FAR	30 days	22/05/28	30/06/28
20	**MSR ERO OIM procurement (as per current MSR ERO schedule)**	**1407 days**	**31/07/20**	**22/12/25**
21	**S2M2 COMPLETE S/C manufacturing and procurement**	**675 days**	**01/12/25**	**30/06/28**
22	**S2M2 OIM Procurement and Manufacturing**	**587 days**	**01/12/25**	**29/02/28**
23	CPS equipment procurement and equipping	240 days	01/12/25	30/10/26
24	CPS subassembly Integration and testing	85 days	02/11/26	26/02/27
25	TCS procurement	400 days	01/12/25	11/06/27
26	Long Lead Items proc.	100 days	01/12/25	17/04/26
27	Structure proc., mfg. & static test	280 days	01/12/25	25/12/26
28	Harness proc. Mfg. inst	412 days	02/02/26	31/08/27
29	OIM PFM AIT including CPS integration in OIM PFM	227 days	01/03/27	11/01/28
30	PIU FM procurement & MAIT and OIM functional test	347 days	02/11/26	29/02/28
31	**HE-R1000 Procurement and Manufacturing**	**587 days**	**01/12/25**	**29/02/28**
32	Structure manufacturing	261 days	01/12/25	30/11/26
33	P/L instruments delivery to AIT Contractor & integration	129 days	01/01/27	30/06/27
34	Harness proc. Mfg. inst	412 days	01/12/25	29/06/27
35	TCS integration	88 days	01/09/26	31/12/26
36	power Subsystem integration including SA and SADM	44 days	01/12/26	29/01/27
37	Avionics Test Bench integration	195 days	01/09/26	31/05/27
38	Telecomm subsystem integration	86 days	01/02/27	31/05/27
39	propulsion subsystem integration	64 days	01/01/27	31/03/27
40	Bus units integration (mech/elect) & alignment	76 days	01/04/27	15/07/27
41	BUS and S/C IFT	55 days	16/07/27	30/09/27
42	BUS & S/C prep to Environmnetal test & MOI-COG det	21 days	01/10/27	29/10/27
43	HE-R1000 Environmental testing	45 days	01/11/27	31/12/27
44	Alignments and check out	21 days	03/01/28	31/01/28
45	HE-R1000 QAR	21 days	01/02/28	29/02/28
46	**Spacecraft level**	**88 days**	**01/03/28**	**30/06/28**
47	Mating and testing (incl. SVT)	58 days	01/03/28	19/05/28
48	S2M2 S/C QAR and FAR	30 days	22/05/28	30/06/28
49	**Margin**	**65 days**	**03/07/28**	**29/09/28**
50	**Delivery to ESA and Launch Campaign and Launch**	**44 days**	**02/10/28**	**30/11/28**

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Figure 7-1 Schedule

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